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Research Article

Fretting corrosion of screws contribute to the fixation failure of the femoral neck: a case report

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Jiajun Luo[1], Sara Ajami[1], Hai-Ming Yu[2], Shuanhong Ma[3], Shen-Mao Chen[1], Feng Zhou[3], Pei-Wen Wang[2], Xue-Dong Yao[2], Chaozong Liu[1] ✉

[1]Division of Surgery & Interventional Science, Institute of Orthopaedic & Musculoskeletal Science, University College London, Royal National Orthopaedic Hospital, Stanmore HA7 4LP, UK
[2]Department of Orthopaedics, Second Affiliated Hospital of Fujian Medical University, Quanzhou 362000, People's Republic of China
[3]State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China
✉ *E-mail: chaozong.liu@ucl.ac.uk*

Abstract: Fretting corrosion of metal implants has been associated with implant failure and revision surgeries. This report describes the fixation failure of a femoral neck fracture in a 61-year-old male patient due to corrosion of three cannulated screws. Radiographic evaluation at the time of primary surgery demonstrated well-positioning of the cannulated screws. The patient had no significant medical comorbidities at the time of surgery. However, screw loosening and avascular necrosis were diagnosed after 5 years. At the revision surgery, inflammatory serological markers, C-reactive protein and erythrocyte sedimentation rate showed no signs of infections, and screws were retrieved. Scanning electron microscopy observations showed that all screws were subjected to fretting corrosion which led to discolouration, pitting attack, and cracking. Thus, Fretting corrosion may have contributed to the failure of the fixation of screws.

1 Introduction

Hip fracture is a major public health issue and is likely to be continued as one due to the ageing population resulting in a significant amount of morbidity and mortality. A fragility fracture is the commonest type of fracture in women 60 years or older and in men 65 years or older with osteoporosis or osteopenia. Fractures of femoral neck generally necessitate surgical intervention with either internal fixation or arthroplasty [1]. Treatment of choice varies according to the degree of displacement, patients' age, bone quality, level of activity, and premorbid mobility [2, 3]. Internal fixation remains the treatment of choice for patients without degenerative changes in the hip joint, and also in displaced fractures in the younger patients, where preservation of the femoral head is the priority [4]. The anatomical reduction can be achieved using cancellous screw fixation or dynamic hip screw (DHS). The DHS prevents varus displacement or rotational instability due to the locking plate feature; whereas the cancellous screws offer less invasive surgery, shorter operation time, and less blood loss when compared with DHS [5–12]. Despite the advantages, a failure rate of 20–36% has been reported for cancellous screws [13, 14]. So far, avascular necrosis (AVN), screw migration, non-union of the fracture, and infection have been reported as main factors contributing to the failure [2, 15]. Here, we have reported failure of the internal fixation of a displaced fracture due to fretting corrosion of the screws.

2 Methods

2.1 Case presentation

In this case, a 61-year-old male (170 cm height and 66 kg weight) patient's right hip was internally fixed due to displaced femoral neck fracture 4 h after the accident. Multiple 7.3 mm cannulated screws (Ti-6Al-7Nb screws, DePuy Synthes) were used to fix the femoral neck fracture. Two short thread screws and one long thread screw, in this case, in parallel, and one of the screws was stabilised with a washer (screw 1). At the time of the surgery, patient had no significant medical comorbidities. After 1 year of implantation, patient reported pain and reduced mobility of the joint. The 5 years post-operative computed tomography (CT) showed evidence of bone resorption, screw loosening, and AVN of femoral head (Fig. 1). Ultimately, the patient underwent total hip replacement procedure, and the screws were retrieved. Before the revision surgery serological inflammatory markers, C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) were examined to identify the presence of periprosthetic joint infection. A CRP of 0.83 mg/l and ESR of 16 mm/h were found, and thus no signs of infection.

2.2 Macroscopical examination

All screws were macroscopically examined to identify the presence of wear and corrosion degradations into two visually divided sections including the shaft and thread. Detailed microscopic analysis of regions of interests was carried out using a scanning electron microscope (SEM, JSM-5600LV, JEOL company, Japan) equipped by electron dispersive spectrometer (EDX). This allowed examination of particular features of the worn and corroded surfaces.

3 Results

All screws were cleaned with distilled water before analysis to remove any biological debris such as blood. Corrosion and fretting damages were identified according to protocol reported by Goldberg *et al.* [16]. A region was described corroded when altered optical properties including discolouration and loss of reflectivity were observed. Fretting was defined as mechanical damage to surfaces, resulting in plastic deformation and material removal, or burnishing resulting in regions of increased reflectivity.

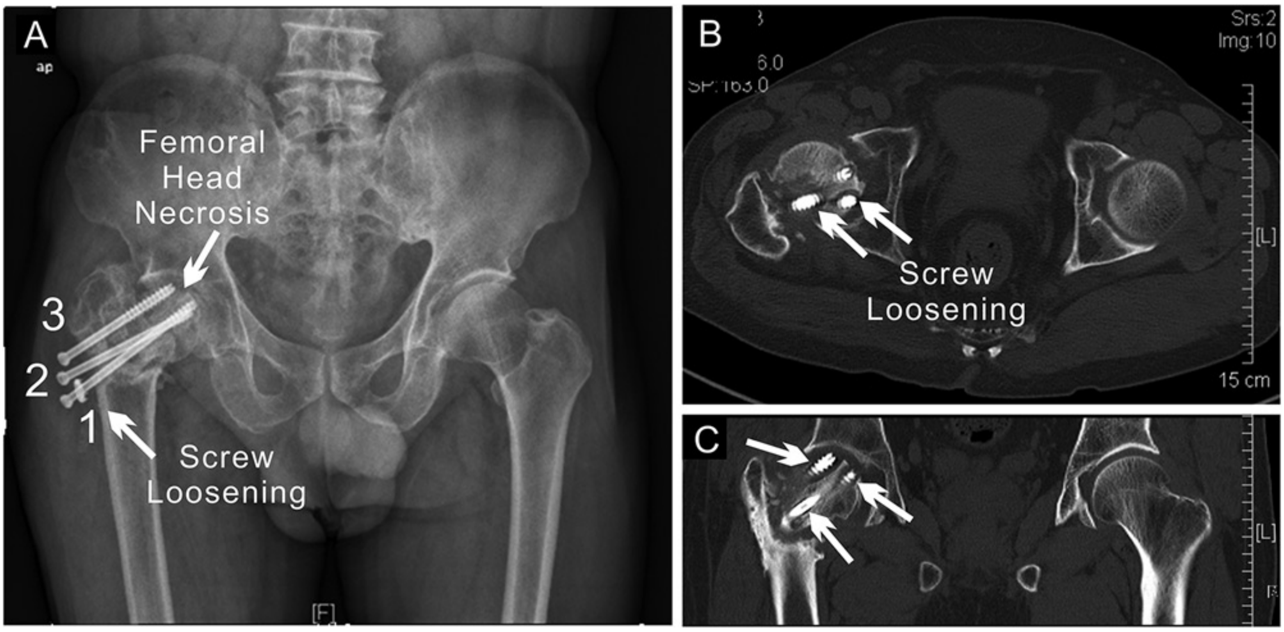

Fig. 1 *CT scan of screws loosening and AVN after 5 year implantation*

a Front view of 1–3 screws location
b Top view of CT scan, gap at bone–implant interface can be detected clearly
c Obvious femur head resorption is observed adjacent screws

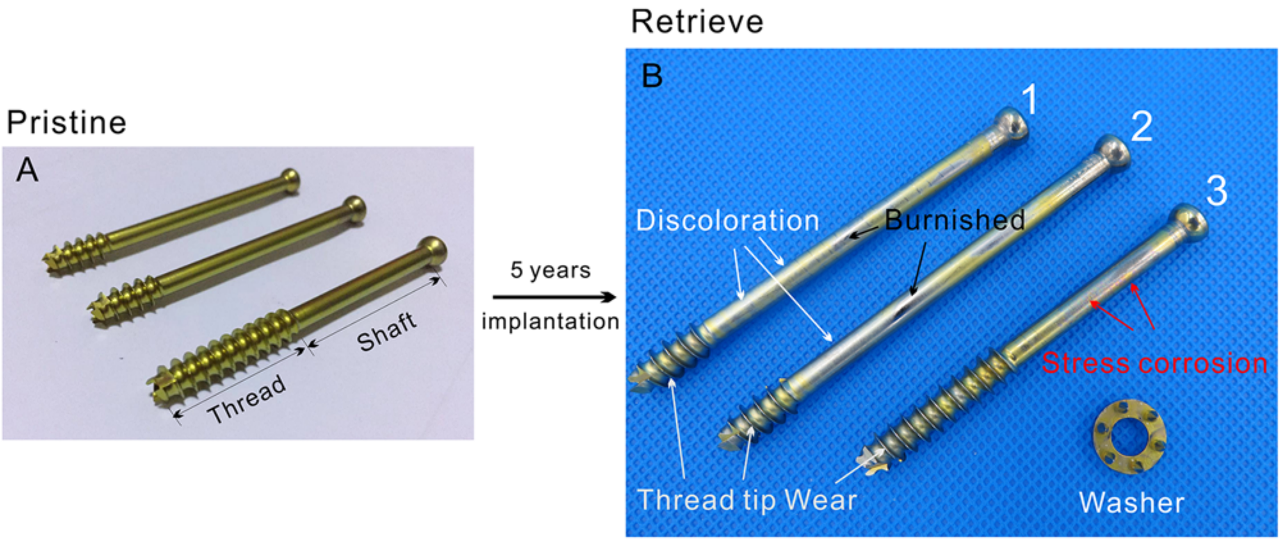

Fig. 2 *Comparison optical image of pristine screws and degradation of screws*

a Pristine screws
b Retrieval screws discolouration located on both shaft and thread areas

Discolouration and removal of the gold oxide layer were observed in all screws as a result of long-term fretting (Fig. 2). Burnished regions were also found on the bare titanium (Ti) substrate in screws 1 and 2. When screws 1 and 2 were examined under SEM, it was found that the screw shaft was covered with randomly ordered scratches with the length of more than 100 µm (Fig. 3). Higher magnification images of the scratches showed irregular pitting which may have formed by erosion over time. Regions with no evident signs of scratches were also examined, and the uniform distribution of pits was found on the surface of the screws (Fig. 4). Furthermore, the size of the pits was in the range of 10–20 µm.

Microscopic analysis of screw 3 showed cracking all over the shaft surface (Fig. 5). This is characteristic of stress corrosion cracking. Some of the cracked regions were featured with a dark (a) and bright appearance under SEM (b). EDX analysis of both regions demonstrated the presence of oxygen (O), aluminium (Al), Ti, and carbon (C) elements. The high percentage of O (region A: 62% and region B: 51%) indicated exposure of O diffused layer. The considerable percentage of Al element (region a: 3% and region b: 5%) suggested decreased thickness of the oxide layer and exposure of bare Ti alloy. Furthermore, high contents of O and C on screw 3 indicated the presence of biological elements such as protein. The topographical differences between fretting corrosion and stress corrosion are shown in Fig. 6.

Evaluation of the threaded part of the screws revealed discolouration and deformities at the thread edge (Fig. 7). The SEM image showed a crack line running through the edge and different topographies in the adjacent surfaces (a and b). Rough surface and micro-sized pits were intensively distributed on one

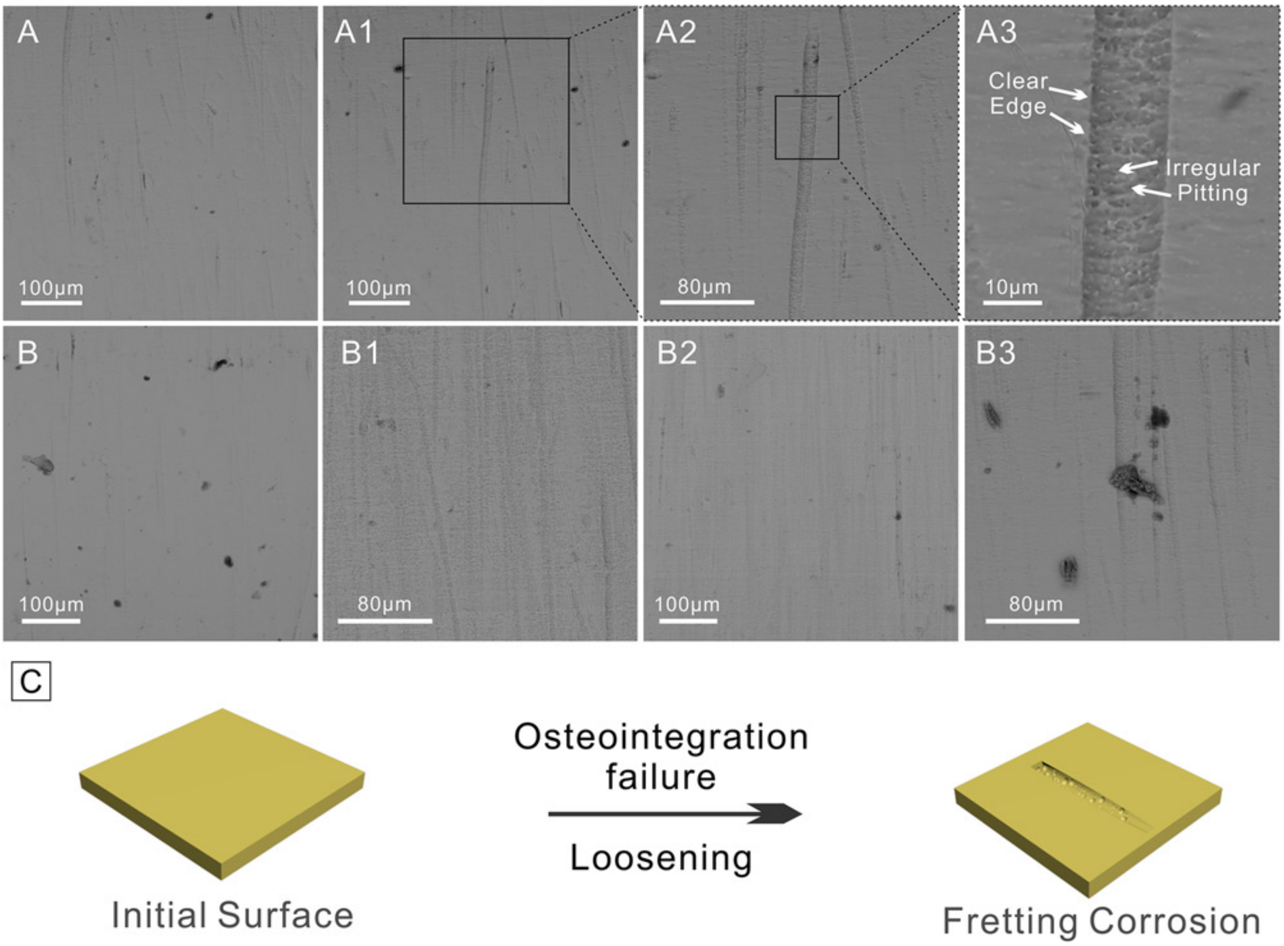

Fig. 3 *SEM images of shaft areas on screw 1*

a Widely and randomly distribution of fretting scratches on screw 1 shaft features of fretting scratches (A1), (A2), and (A3)
b Scratches distribution on screw 2 shaft (B), (B1), (B2), and (B3)
c Schematic illustration of fretting scratches formation

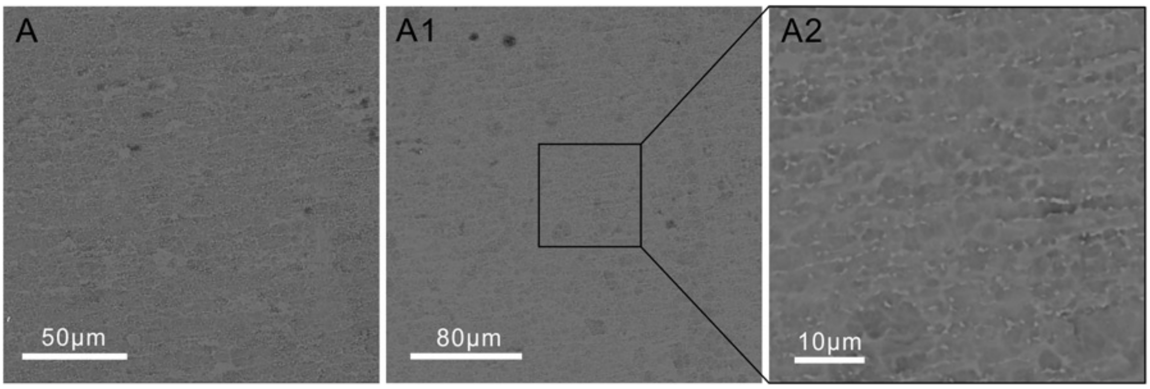

Fig. 4 *Fretting corrosion morphology features on screws 1 and 2 shinny (burnished) areas*

a Screw 1 widely distribution
b, c Specific features on screw 2 (A1) and (A2)

side (side a), whereas no evident pits were found on the other (side b).

The EDX result showed high concentrations of O (54%), Ti (29%), and other corrosion and biological elements such as C (11%), calcium (1%), and phosphorus (1%) on the side a. However, side b showed depletion of O and high concentration of Ti (11%) and Al (89%) confirming removal of the oxide layer and bulk exposure of the substrate. During the insertion, surface areas labelled 'a' had the initial contact with the bone and were prone to more stress leading to insertion wear. As a result, the bone wear debris was found on these surfaces as confirmed by EDX.

4 Discussion

This paper reported the failure of three internal fixation screws retrieved from a patient after 5 years in service. Here, we have visually and microscopically investigated for signs of degradations

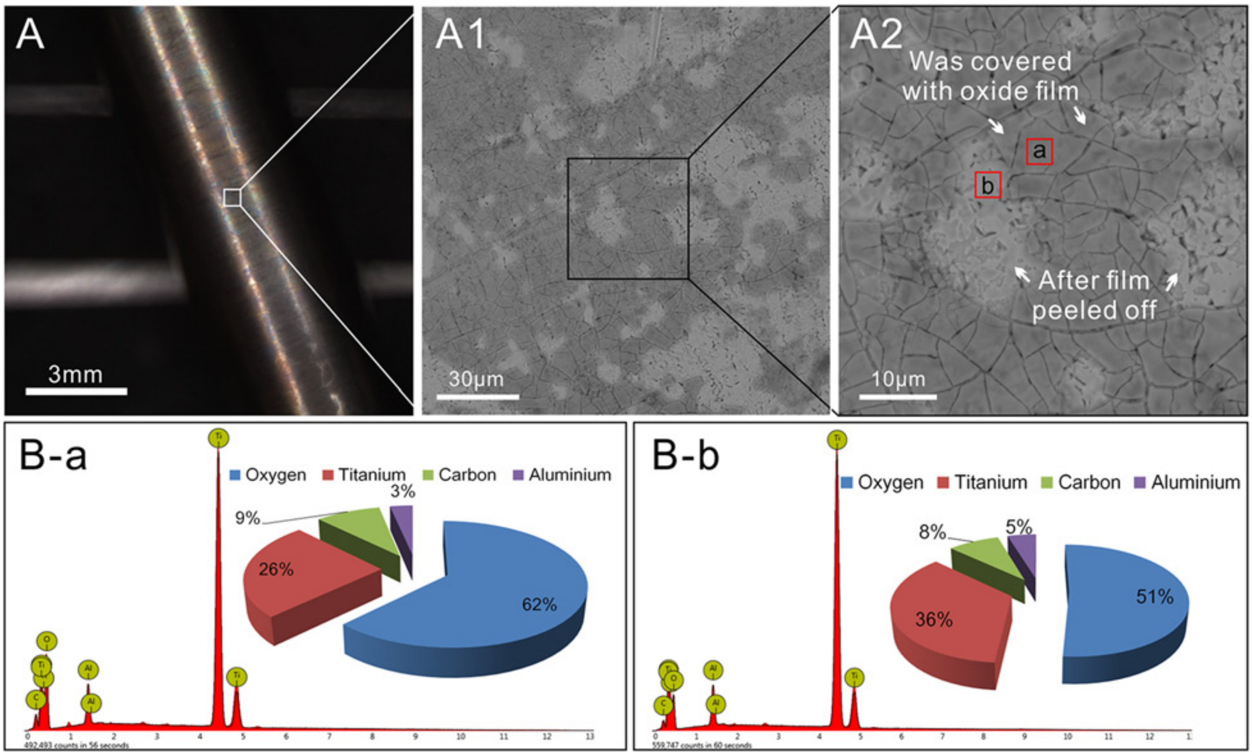

Fig. 5 *Stress corrosion on screw 3*

a Optical image, SEM images of stress corrosion areas (A1 and A2)
b Chemical composition of the areas a and b (B-a and B-b)

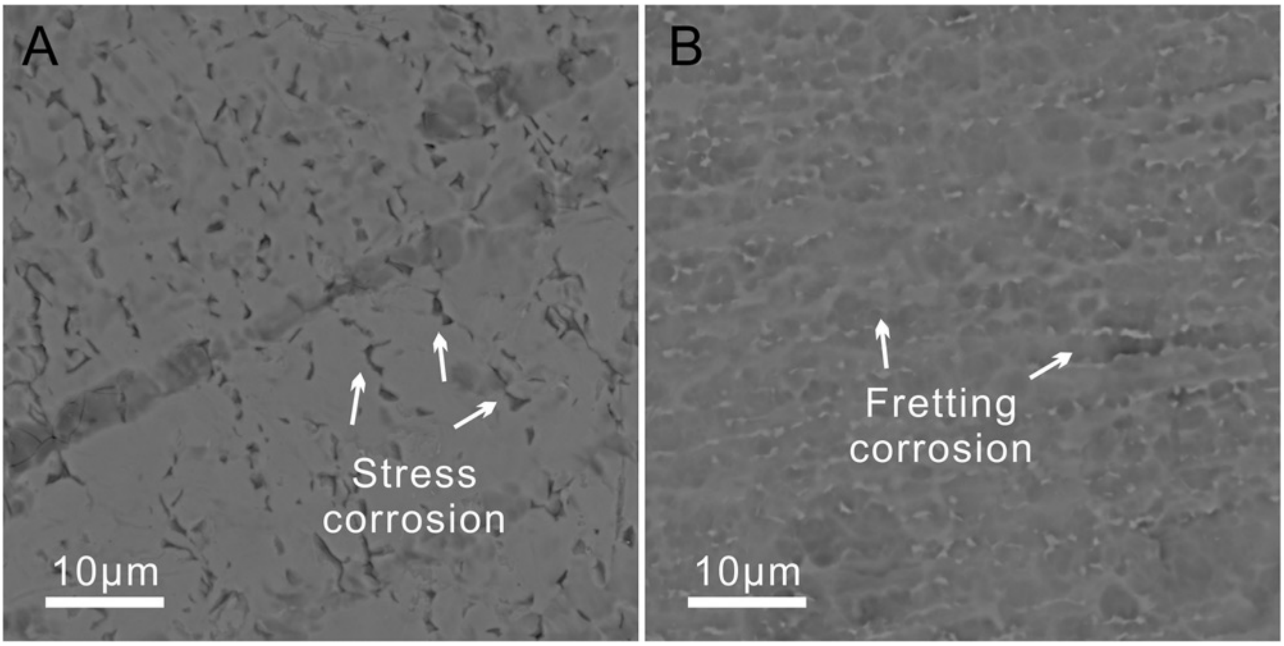

Fig. 6 *Comparative SEM images*

a Stress corrosion topography featured with angle edge cracks
b Fretting corrosion topography

(Table 1). The common mechanism of failure in all screws was fretting corrosion. Typical features observed among the screws include pitting attack, scratches, and cracking.

Ti and its alloys are vastly used in orthopaedic applications due to a combination of attractive properties such as high corrosion resistance, good biocompatibility, and mechanical properties. The corrosion resistance of Ti is the result of the spontaneous formation of a 3–10 nm passive Ti oxide (TiO_2) film on its surface when in contact with O [17]. Under normal physiological conditions, TiO_2 has the ability to form. However, abnormal cyclic loading, acidic environment, implant micromotion, and their combined effects lead to the permanent breakdown of the oxide layer and active corrosion of the bare metal. The most common types of corrosions in Ti prostheses can be classified as pitting, fretting, galvanic, and crevice corrosion. When the passive TiO_2 layer on a flat surface is disrupted by acid, pitting corrosion

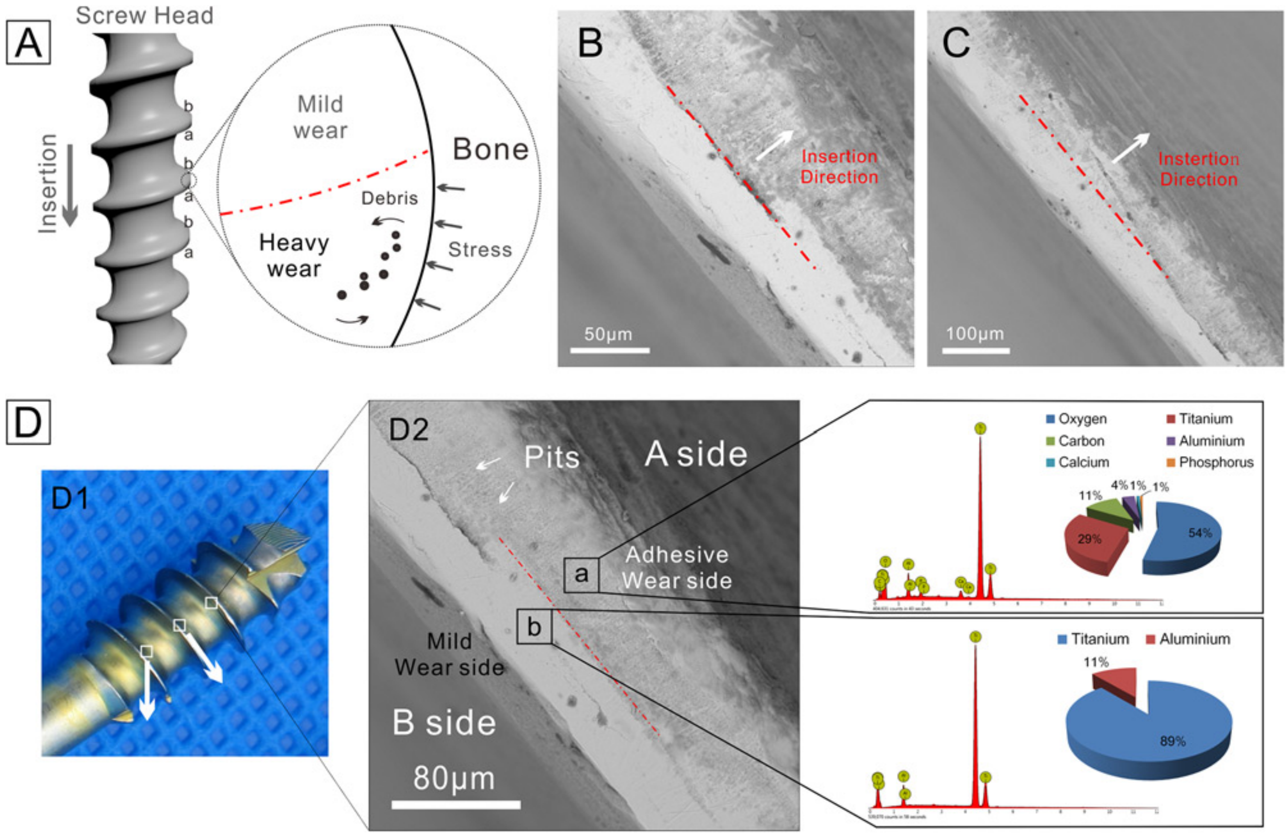

Fig. 7 *Schematic images of insertion wear*

a Schematic illustration of insertion wear mechanism at thread tip
b, c SEM images of wear scar on the threads tip (B) and (C)
d Optical image and EDX analysis of thread tip on area a and b (D, D1 and D2)

Table 1 Main degradation of screws 1–3

	1	2	3
shaft (burnished areas)	fretting corrosion	fretting corrosion	stress corrosion
shaft (discolouration)	fretting corrosion	fretting corrosion	stress corrosion
threads	insertion wear	insertion wear	insertion wear

occurs. Repeated micromotion or friction between the TiO_2 layer and another material causes mechanical wear and break ups of the passive layer and it is known as fretting corrosion. The three screws reported in this paper were all moderately affected by fretting corrosion. Discolouration, dullness, and burnishing were observed in all three screws. Micromotions causing the fretting corrosion can be attributed to inadequate mechanical fixation at the time of surgery or reduced bone healing capacity due to AVN.

Moreover, a cracking pattern was also observed in screw 3 which indicates the presence of stress corrosion cracking. However, the mechanism for crack initiation and propagation is not clear. It has been suggested that cracks could be initiated by fretting and propagate by stress corrosion cracking [18]. Bundy reported that crack like phenomena can occur *in vivo* at a stress level of σy (yield stress) after a short period [19].

The patient, in this case, underwent parallel screw fixation. This conventional method does not always provide adequate fixation strength, especially if low-quality bone or osteoporosis is present [20]. However, the patient had no history of osteoporosis. Apart from that, insertion of screws nearby of each other with entry points localised in thin region of the cortex could cause instability in these constructs when subjected to various stresses, anteroposterior bending, and torsion [21]. Thus, resulting in micromotion between screws and the bone, and leading to the displacement of the screws. Impaired implant stability and micromotions above 50–100 μm may negatively influence osseointegration and bone remodelling by forming fibrous tissues and inducing bone resorption at the bone–implant interface. Several other factors can also affect the strength of femoral neck fixation using multiple screws including fracture communication, fracture level, moment of arm (distance from the centre of the femoral head to the fracture line), and angle of inclination [22].

It is advocated that fracture reduction and stable fixation should be performed as a surgical emergency in an attempt to restore blood supply to the femoral head and prevent further complications including AVN and non-union. The incidence of the named complications has been reported to be 10–30 and 20%, respectively [23–26]. AVN and non-union of the femoral head led to the segmental collapse of the head which predispose to secondary hip joint degenerative changes, necessitating revision surgery. Lakkol *et al.* [27] evaluated the failure rate among fixation devices for undisplaced fracture neck of femur in 52 patients and found 36% of patients had reoperation. The reason for the revision was failure of fixation in 88% and AVN in 11% of the patients. Manohara *et al.* [28] also reviewed the outcomes of cancellous screw fixation for undisplaced femoral neck fracture in 96 patients. The patients were followed up for a mean of 39 months, 8 underwent revision for AVN of the femoral head ($n = 5$), and non-union/implant failure ($n = 3$). The case reviewed here also suffered from AVN. The fracture was treated 4 h after the incidence. Khoo *et al.* [4] reported no cases of AVN when the fracture was reduced and fixed within 6 h but the incidence increased with increasing time interval. The vascularity of the head can be affected by initial trauma and also inadequate fracture reduction. However, no signs of disrupted blood supply and AVN was observed at the time of the surgery in this case.

In another clinical study, non-union, osteonecrosis, stress fracture of the subtrochanter, excessive pull-out of a screw, and deep infection were major complications reported for undisplaced femoral neck fractures [2]. Bacteria present on the surface of the implant or biofilm formation can cause pitting and discolouration of implants. To determine if periprosthetic infection was a contributing factor to the failure of the screws, we analysed the serum biomarkers before implant removal. For any patient undergoing revision, total joint arthroplasty, ESR, and CPR are standard screening tests regardless of the cause of failure. Ghanem *et al.* showed that CRP of 10 mg/l and ESR of 30 mm/h have a sensitivity of 97.6% if combined [29]. We found CPR of 0.83 mg/l and ESR of 16 mm/h which were not indicative of infection.

Corrosion of the metal implants may jeopardise the integrity of the surrounding tissue and mechanical stability of the implant. When the metal ions are released from the implant surface or particulate metallic wear, they either remain in the intercellular spaces near the site where they were released or migrate systemically. The release of these ions activates the immune system and subsequent release of proinflammatory factors and chemical mediators which have shown to result in a cascade of events leading to periprosthetic osteolysis. In the present investigation, fretting promoted the removal of the TiO_2 layer and release of oxide and metal debris which may also have contributed to osteolysis and loosening.

5 Conclusion

In conclusion, this case study reports documents the failure of a femoral neck fixation using parallel cannulated screws. Inadequate fixation and micromotion appeared to cause fretting corrosion in these constructs and subsequently leading to the failure of the screws. Given the advantages of screw fixation for femoral neck fracture, studies are needed to develop Ti surfaces with enhanced corrosion resistance and bio-functionality to establish the longevity of these screws. In particular, TiO_2 nanotubes fabricated on Ti implant surfaces are attracting increased attention due to their superior corrosion resistance, osteoconduction, and osteointegration. The TiO_2 nanotubes not only reduce the micromotion at the bone–implant interface but can also be used as a delivery platform for drugs including antibacterial agents, growth factors, and inorganic bioactive elements [30].

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